

Heat Accumulation: An Easy Way To Anticipate the Flowering of Southern Pines

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ABSTRACT—Accumulation of degree-day heat sums accounts for most of the year-to-year variation in dates of peak pollen shed by slash (*Pinus elliottii* Engelm.), longleaf (*P. palustris* Mill.), loblolly (*P. taeda* L.), and shortleaf (*P. echinata* Mill.) pines. During 19 years of observation for longleaf and 6 years for each of the other species, the average deviation of observed from predicted peak date was four days or less. Slash pine had the greatest range among years in date of peak flowering (45 days), followed by longleaf (40 days), loblolly (23 days), and shortleaf (20 days). Male strobili of slash pine developed without pause, except on cold days, after their emergence in late November or early December. Longleaf, however, had a period of winter dormancy that averaged about one month, and loblolly and shortleaf were dormant about two months during winter. Only the pollen shed periods of longleaf and loblolly pines overlapped during this study. Differences in heat and dormancy requirements apparently preclude overlap between longleaf and slash pines, or between shortleaf and any of the others.

Among the four principal species of southern pine, slash normally flowers first, then longleaf, loblolly, and shortleaf (Dorman and Barber 1956). The date when a species reaches peak pollen shed varies considerably from year to year and from place to place in the same year. This paper presents a technique for anticipating the time each species will reach peak pollen shed. The procedure can alert geneticists, foresters, and seed orchard managers as to when pollen shed by any of the four species is imminent.

The time of pollen shed by pines is governed largely by air temperatures during the days or weeks before flowering—cool weather slows and warm weather hastens the development and dispersal of pollen from staminate strobili (Boyer 1973, Duffield 1953, Fielding 1957, Snyder 1961, Wang et al. 1960). Heat units accumulated above an appropriate base temperature, a

method used to follow the development of agricultural crops (Arnold 1960, Holmes and Robertson 1959, Major and Johnson 1975, Partridge 1947), can be used to anticipate the date on which southern pines will achieve peak pollen shed. To determine the time of greatest pollen shed for a species, the base temperature above which flower development occurs and the average date that flower development starts must be known.

After staminate flower buds begin to enlarge, the maximum temperature is recorded each day, the base temperature appropriate for each species is subtracted from it, and all positive values are added from day to day. When this degree-day heat sum reaches a certain level, flowering will occur.

The Study

From 1957 to 1975, air-borne pollen from longleaf pines was collected by pollen traps placed in a weather instrument shelter on the Escambia Experimental Forest in southwest Alabama. The date when the most pollen was trapped was recorded each year. Daily maximum temperatures were obtained from the Brewton, Alabama, NOAA weather station, 3.8 miles north-northeast of the study area.

To check for variation among species in heat sums required to reach peak shed, pollen from individual slash, longleaf, loblolly, and shortleaf pines was observed on the Escambia Experimental Forest starting in 1970. Three clusters of male flowers on each of five (1970), six (1971), seven (1972), and eight (1973 through 1975) sample trees per species were tagged annually, and the date of maximum pollen shed by each cluster was recorded. The peak day for a species was the mean date of maximum pollen shed for all clusters on all trees. Standard deviation and range of peak pollen shed day also were determined for each species each year.

To determine whether the required heat sums vary from place to place, pollen traps were placed in natural longleaf stands in the mountain province of Coosa County, Alabama, from 1971-75; the sandhills in Moore County, North Carolina (1967-68); and the coastal plains in Bladen County, North Carolina (1974-75). In Coosa County, maximum daily temperatures were obtained from a NOAA weather station 11 miles northeast of the study area. In Bladen County, temperatures were recorded at the study site. In Moore County, temperatures were obtained from a weather station about seven miles from the study site.

Table 1. Base temperature, starting date, and average heat sums to peak flowering for four species of southern pine on the Escambia Experimental Forest. Longleaf values are for 1957 to 1966; values for the other species are for 1970-1975.

Species	Base temperature Degrees F	Starting date for heat sums	Heat sums to peak flowering		
			Average	Std. dev.	Coef. var.
			-Degree-days-	Percent	
Slash	55	5 Dec.	735	39.8	5.4
Longleaf	50	31 Dec.	1,208	46.3	3.0
Loblolly	55	1 Feb.	636	69.3	10.9
Shortleaf	55	31 Jan.	1,140	133.9	11.7

Pollen shed data were analyzed to determine the best combination of base temperature and starting date for degree-day accumulation for each species. Standard deviation and coefficient of variation, both of which are needed to select the best base temperature, in yearly heat sums to peak pollen shed were obtained for combinations of base temperatures of 40°, 45°, 50°, 55°, and 60°F with a number of starting dates between the first of November and the middle of February. The best starting date is that with the smallest, standard deviation (Boyer 1973). Reliability of degree-day heat sums in predicting the date of peak pollen shed was tested for all Escambia Experimental Forest data by comparing the observed date of peak pollen shed with the expected date.

Testing the Method

The average degree-day heat sum to peak pollen shed varied considerably among species (table 1). Average starting dates for effective heat sum accumulation were December 5 for slash, December 31 for longleaf, January 31 for shortleaf, and February 1 for loblolly (fig. 1). The standard deviation of annual sums was least for slash pine, probably because its staminate strobili had no winter dormancy. Buds of staminate strobili of all four species normally emerge in late November and early December. The buds of slash pine strobili apparently continued development through the winter whenever temperatures were warm enough. Those of both loblolly and shortleaf pine had a period of winter dormancy averaging nearly two months. Longleaf pine buds were dormant about one month. This aspect of flowering suggests that slash pine had a tropical origin and has existed in temperate regions for less time than the other three species. Loblolly and shortleaf pines apparently have evolved

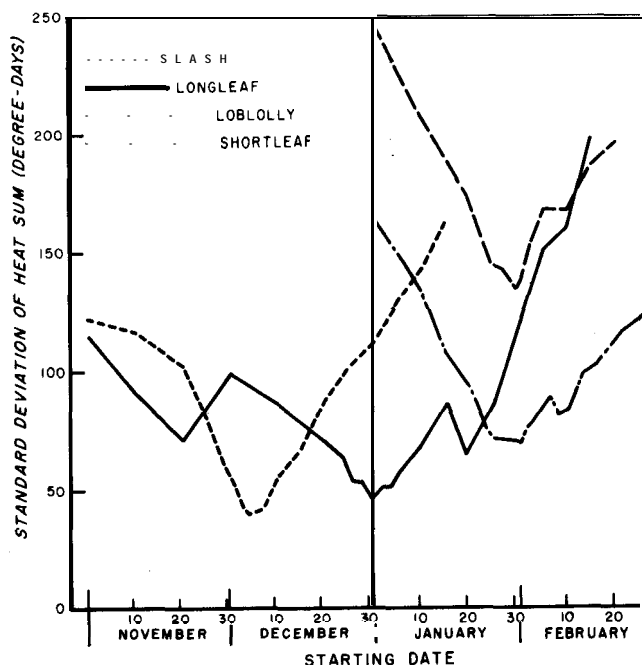


Figure 1. Effect of changes in starting date for heat sum accumulation on standard deviation of degree-days to peak flowering of four species of southern pines in southwest Alabama. The lowest value for each species indicates the average starting date.

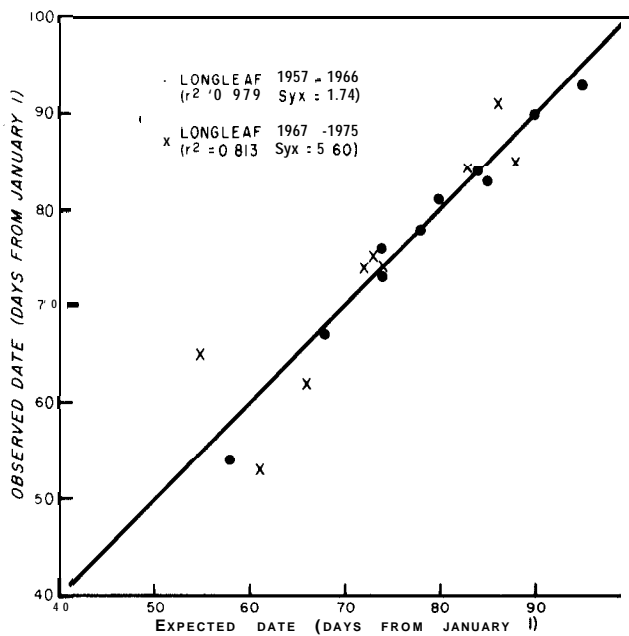


Figure 2. Relationship of observed to expected date of peak flowering for longleaf in southwest Alabama from 1957-66 and 1967-75.

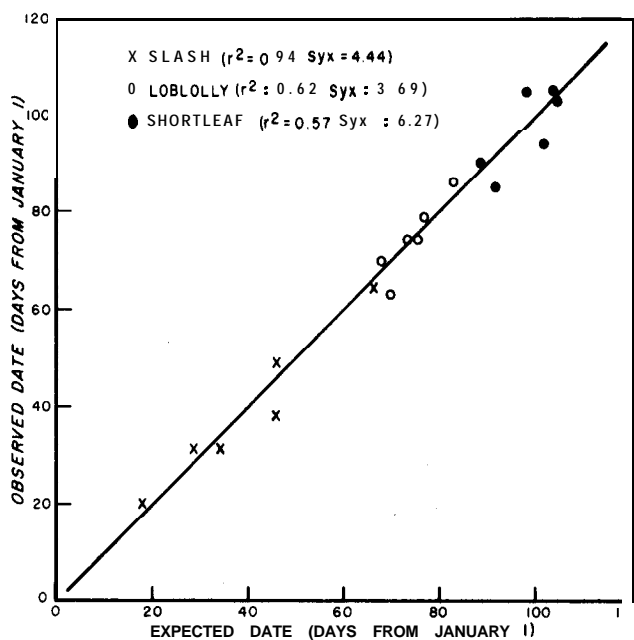


Figure 3. Relationship of observed to expected date of peak flowering for slash, loblolly, and shortleaf pines in southwest Alabama (1970-75).

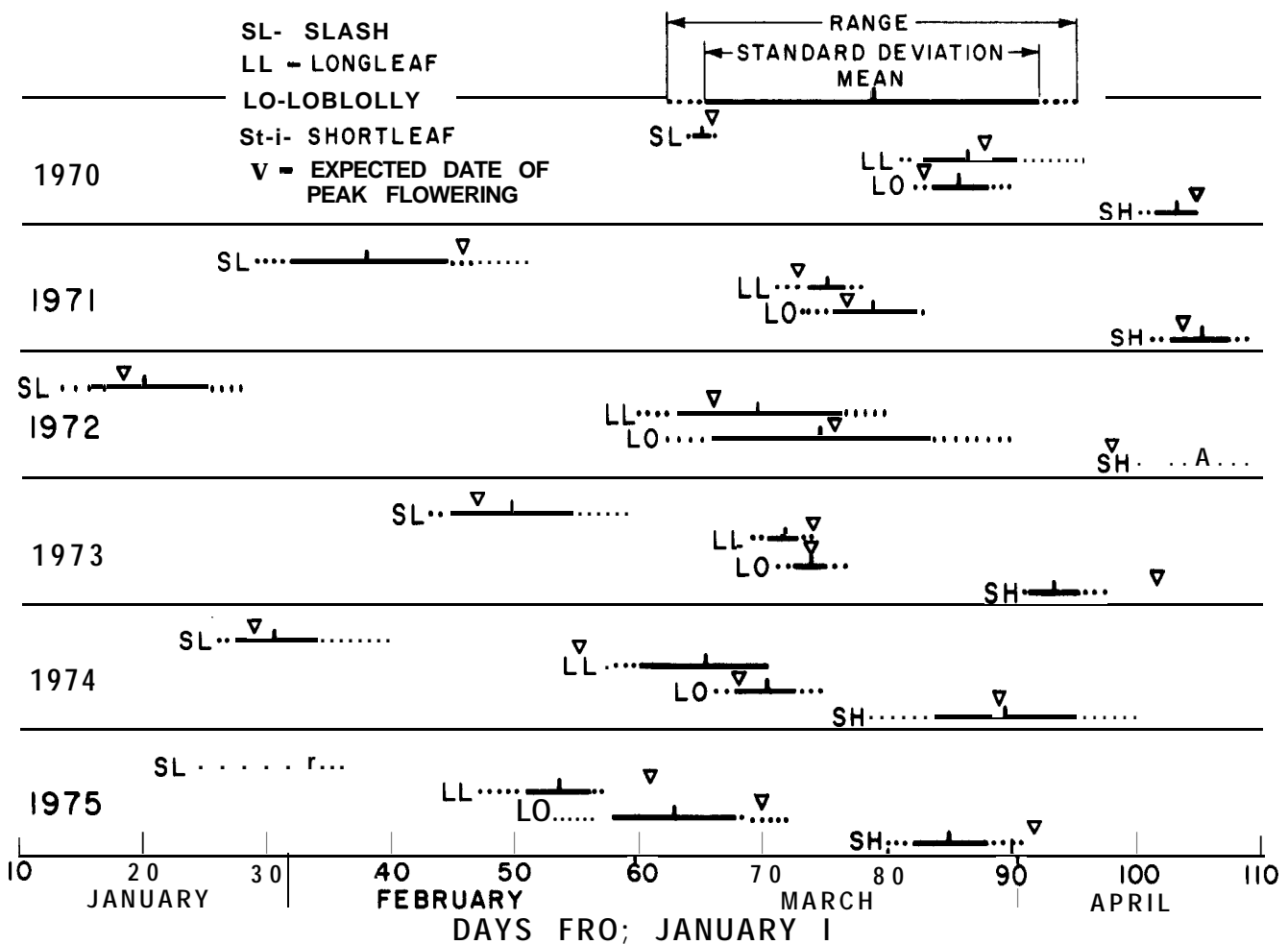


Figure 4. Time of flowering by four species of southern pines in southwest Alabama (1970-75). Mean, standard deviation, and range of peak date by sampled flower clusters are shown for comparison with date of peak flowering predicted from heat sum accumulations.

much longer under temperate climatic conditions than slash; **longleaf** pine appears to be intermediate.

The best base temperature for **longleaf** pine was 50°F; 55°F was somewhat better for slash, loblolly, and shortleaf pines. A single base temperature, either 50° or 55°F, can be used for all species with little sacrifice in accuracy. Using one base temperature is **simpler than** using two and changes the coefficient of variation by less than 1 percent in each case.

From 1971-75, **longleaf** pine in Coosa County reached peak pollen shed an average of 21 days later than **longleaf** on the Escambia Experimental Forest. However, degree-day heat sums from a 50°F base and January 1 starting date averaged 1,203 in Coosa County. Heat sums for **longleaf** pine in North Carolina averaged 1,111 degree-days for the two years in the sandhills, and 1,012 degree-days for the two years in the coastal plains.

Reliability of the Method

A heat sum of 1,208 degree-days accounted for 98 percent of the year-to-year variation in flowering date of **longleaf** pine from 1957-66 (fig. 2). The average deviation of observed from expected date of peak pollen shed was 1.3 days, **considerably** more than the 0.3 days obtained by using degree-hours (Boyer 1973), but close enough for any practical purpose. The 1,208 degree-day heat sum accounted for 81 percent of the variation in date of peak pollen shed from 1967-75; the average deviation of observed from **expected** date was 3.9 days. However, most of this deviation was caused by two years (1974 and 1975) which had unusually large deviations of 10 and 8 days. The average number of degree-days to peak flowering for 1967-75 was 1,249, 3 percent above the average for 1957-66.

Degree-day heat sums also accounted for 94 percent of the year-to-year variation in date of peak pollen shed by slash, 82 percent by loblolly, and 57 percent by shortleaf pines (fig. 3). The average deviation of observed from expected flowering dates over the six years of record was 3.2 days for slash, 2.7 days for loblolly, and 4.3 days for shortleaf pine.

When pollen, Shed-patterns of the four species were compared, only **longleaf** and loblolly pine overlapped during the six years of observation (fig. 4). In 1970; pollen shed by loblolly peaked slightly ahead of **longleaf** pine. **Longleaf** peaked ahead of loblolly in all other years. The earlier **longleaf** flowered, the greater was the gap between its peak day and that for loblolly. **Longleaf** requires a larger heat sum for flowering than loblolly but **compensates** by beginning development earlier in the winter. The difference between the two species depends largely on January temperatures; heat accumulated in January promotes **longleaf** flower development but has little effect on loblolly pine. A total of 368 or more degree-days above 50° F in January will allow **longleaf** to flower at the same time as or before loblolly pine. If the sum is smaller, loblolly flowering will peak before **longleaf** pine. In a year when December and January temperatures are constantly below the threshold for growth, loblolly pine may flower ahead of both slash and **longleaf** pine. Once dormancy ends, the degree-day heat requirement for loblolly is less than that for any other species. Because of differences in heat and dormancy requirements, significant overlap in flowering between **longleaf** and

slash pine, or between shortleaf and any of the other three species, is very unlikely regardless of winter weather conditions.

Using the Method To Predict Pollen Shed

To predict the date of peak pollen shed in an area accurately, flowering should be observed for at least three years. With the base temperatures and starting dates given in this paper, degree-day sums for a particular stand can be derived from local temperature data. The source of temperature data should be kept constant at a given location, because using different instruments may change results. When degree-day heat sums were obtained from a hygrothermograph on the Escambia Experimental Forest, and a base of 50°F and starting date of January 1 were used, degree-days to peak pollen shed of **longleaf** pine averaged 1,104 according to the hygrothermograph and 1,226 according to maximum temperatures from the Brewton weather station. Over five years in Coosa County, hygrothermograph degree-days to peak pollen shed averaged 1,035, compared with the 1,203 from weather station records.

The day-to-day accumulation of degree-days monitors continuously the progress of flower development without the necessity for frequent field observations. Also, the extent to which development in a particular year departs from the average for a locality is always apparent. The procedure thus provides early warning of the probability of unusually early or late flowering so that preparations can be adjusted accordingly.

Early flowering trees may shed their pollen some 200 to 300 degree-days ahead of the average for the stand. Therefore, actual field checks on flower development should begin when the accumulation is about 300 degree-days short of the sum for peak pollen shed. ■

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